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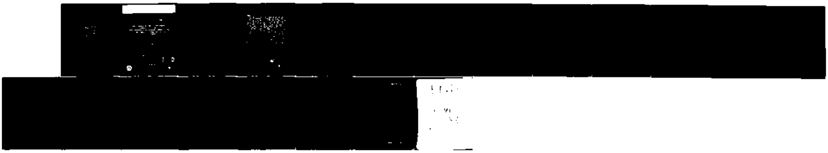

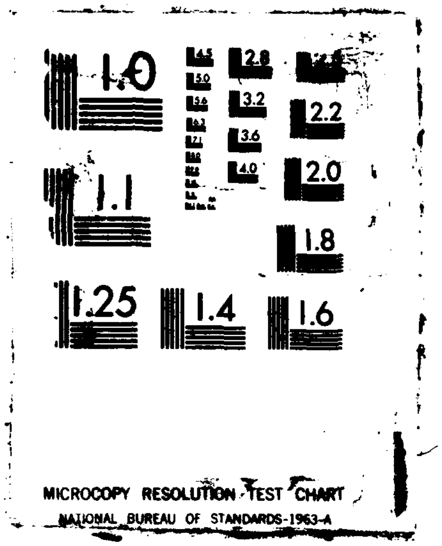
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ENDOGENOUS ERP COMPONENTS ASSOCIATED WITH PERFORMANCE IN SONAR OPERATORS: I. RELIABILITY AND RELATION TO TRAINING

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ENDOGENOUS ERP COMPONENTS ASSOCIATED WITH PERFORMANCE IN SONAR OPERATORS:
I. RELIABILITY AND RELATION TO TRAINING

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SUMMARY

This report is the first step in generating ERP norms that may facilitate the development of a neurometric test battery. Data were collected from 40 sonar operators at the ASW school, San Diego. For each volunteer, EEG was collected at lateral central and temporal leads and signal averaged for 500 msec sweeps. A visual sonar simulation task and auditory information processing tasks were presented to each volunteer. All volunteers completed two test sessions separated by several days. The present results indicate that a visual pattern reversal task and an auditory oddball task generate endogenous ERP components at 150, 200, and 400 msecs that are consistent over test sessions. Furthermore, a test of the hypothesis that amount of training on sonar displays may affect these components was negative. Individual reliability coefficients for the amplitudes and latencies of the components are, however, disappointing with only nine being sufficiently high to warrant their further consideration in generating regression equations for the prediction of performance from ERP measures. The nine components included both latency and amplitude measures, five being associated with visual processing and four with auditory processing. However, as part of this phase of the neurometric program, new methods of data reduction were created and may prove useful in developing a prediction equation.

INTRODUCTION

It is important in research involving the application of new variables that the degree of reliability be determined at the outset. Although some knowledge of the relationship of Event Related Potentials (ERPs) to the cognitive processes involved in information processing is available, there is a paucity of research that directly addresses the question of how well the measurements, whatever they are, will be stable over measurement sessions. In the Neurometric Program, the variables of interest are based on endogenous components of visual and auditory ERPs associated with information processing tasks. They are referred to as endogenous because they occur later than the classical sensory (exogenous) components and purportedly represent the electrical events in the brain that are the basis for the components of information processing, namely, stimulus classification, response selection, and response execution (and sub-categories of these components which are discussed in the Background). The tasks used to evoke the ERPs range in complexity from very simple (keep your eyes open and focused at the dot in the middle of the screen) to relatively complex (signal detection). A fundamental goal of the present study was to demonstrate the reliability of the endogenous ERP components associated with visual and auditory information processing tasks.

A second goal was to demonstrate the degree to which these electrophysiological measurements are related to the amount of training or experience in operating current sonar displays. In the present study the range of training was from 0 (no training) to nineteen years.

The reliability of ERP components was determined by testing each of the 40 male sonar operators on two different days. The dependent variables were the measurable positive and negative sinusoidal waves occurring at selected temporal locations in the range from 100 to 500 msec following a stimulus onset. The method of extracting components of a given ERP consisted of defining windows on the time axis such that individual positive or negative waves could be defined within the windows. A window was thus a measure in milliseconds (e.g., 200) plus and minus a constant (e.g., 50). Such a window represents the range within which a maximal value of positive or negative voltage would then be read. This value then became a dependent variable for a given subject on a given session and for a given task. Pearson product moment correlations between session 1 and session 2 were then obtained for these distributions. Thus, reliability of a given task-related ERP was obtained for several endogenous components specified as N150, P200 and P400. The units of these variables are the amplitudes and latencies of the waves in microvolts and milliseconds.

BACKGROUND

Several measures of central nervous system function are related to performance on information processing tasks and decision tasks. A large body of literature on the subject now exists and applications of the technology are beginning to occur in some fields such as in the clinical area, for example, where neurometric test batteries are routinely used in patient assessment (1). This approach consists of (a) identifying features of electroencephalographic activity that differentiate learning-disabled from normals, (b) developing a set of norms based on these measures, and (c) developing a culture-free test that will predict which learning areas a child is likely to find difficult. The tests are reported to be sufficiently accurate to discriminate between learning-disabled and normal children (1).

The application of brain electrophysiological measures to personnel selection in the Navy began with studies by Lewis, Rimland & Callaway (2) and Lewis & Rimland (3) at the Navy Personnel Research and Development Center. This work suggested that lateral asymmetry of event-related potentials from the brain is a distinguishing attribute of high performance aviators.

A third report by Schlichting and Kinney (4) at the Naval Base, New London found that sonarmen whose performance was rated highest also showed significant interhemispheric asymmetries in visual ERP amplitude. Those who were rated the lowest did not show these asymmetries. This appears to be consistent with the Lewis and Rimland study of aviators. These studies were stimulated by findings that ERP asymmetry varies with the type of task (verbal or spatial) (5), words vs. nonsense patterns (6), and phonemes vs. pure tones (7). Bright and dull children are also reported to be distinguished by asymmetry (8).

The procedures that were developed by Lewis and Rimland (3) and by Schlicting and Kinney (4) for predicting sonarman performance involved a simple stimulus, a flash of light. There was no information processing associated with the stimulus nor was it imperative, i.e., it did not require any cognitive processes involving decision making. Yet the following conclusions were drawn regarding the use of the flash-evoked visual ERP to predict success among sonarmen: (1) the amplitude of the ERP is small in high performance sonarmen compared to low performance sonarmen, and (2) hemispheric asymmetry was greater for high performance sonarmen.

In a basic research program for the Air Force Office of Scientific Research (11), a number of other associations have been made between ERPs and performance. Tracking, attention, automation, "depth" of information processing, and mental chronometry are examples of tasks that have been evaluated in terms of ERP correlates. These basic research findings have not yet been utilized in the development of a neurometric test battery.

In addition to the asymmetry studies, important new discoveries of relationships between cognitive function and attributes of ERPs have been made. One report (10) relates the timing of decision responses and the P300 component of the ERP.

Generally, the endogenous components occur as part of a complex of components that are related to the components of information processing. These components, ranging in latency from 100 to 800 msec, are very different on at least one dimension which has to do with sensory mode specificity. Whereas the later components are usually considered nonspecific with respect to modality (the response is maximal at the vertex and does not differentiate visual or auditory stimuli), N200 is generally considered modality specific (it is largest over preoccipital areas for visual stimuli and over the vertex for auditory stimuli). Because of the earlier onset and sensory specificity of N200, it may well be more closely associated with stimulus evaluation processes than the later components. In this context, the later components have been described as events that reflect the next stage in information processing which involves memory updating or decision closure. It is, therefore, important that all of these components be included in the development of a prediction equation for the complex cognitive tasks under consideration.

The variable "attention" has been of focal interest in developing selection criteria for combat pilots in the Israeli Air Force (12). To test for this variable, a dichotic listening task was developed and tested over a period of six years. It is described as a refined measure of selective attention which, when coupled with other standard criteria, greatly improves the validity of the selection criteria for these high performance personnel. Unfortunately, the test takes several hours to administer. Coincident with this development has been the refinement of techniques for measuring selective attention with auditory ERPs (13, 14). The relationship between the ERP and pilot performance, as measured in (12), however,is not known.

Most of this work was based on laboratory performance criteria in simulators and can at best be viewed as tentative. The reliability and validity of ERP measures for actual job selection have not been demonstrated.

Taken together, the work on ERP correlates of performance as they might be employed in personnel selection are at least promising, although no detailed studies of their reliability and validity have been done. The present effort is part of a Navy multi-laboratory approach to the question of how to use the ERP technology to improve personnel selection for jobs requiring unusual skills in attention and decision making. A summary of the over-all philosophy and a detailed explanation of the techniques can be found in (9).

In summary, the studies of ERPs as they are related to cognitive function and to performance provide enough evidence to continue the process of developing a neurometric test battery. Following the general procedures developed for the clinical appraisal of children, it is conceivable that a set of ERP measurements obtained from prospective aviators, sonar operators, or Combat Information Center personnel and compared to norms from a sample of successful personnel will yield an acceptable prediction equation. Cut-off points would then be set based on supply and demand for such critical operators which could decrease the number of failures in critical assignments.

The current study is the first part of a series of studies that are intended to provide the best measurements of endogenous ERPs for the purpose of predicting high or low performance on the job. Other studies in the series will provide detailed information on other tasks: (1) a dotdensity discrimination task which approximates a sonar display task, and (2) a different auditory discrimination task involving short interstimulus intervals.

METHODS

Visual Tasks: The visual tasks consisted of three progressively difficult parts. First the subject was presented a video screen with a non-contingent alternating checkerboard (ACB). This was similar to that used in clinical settings for diagnosis of visual system anomalies. The subject is asked to merely attend to the screen. The test required three minutes to complete. The second and third parts of the task consisted of the "oddball" paradigm which is routinely used in research involving ERPs. A background checkerboard pattern (BGP) with a 500 msec duration occurred on 80% of the trials. The remaining 20% of the trials consisted of a mirror image of the background pattern. Designated the reversal pattern (RVP), the subject was required to recognize and count the number of "oddball" occurrences. The subject sat in a position such that his eyes were one meter from the screen; for task number one (ACB) he was instructed to simply look at the screen; during task number two (BGP) the subject was required to decide whether the pattern had reversed; finally, for task number three (RVP), the subject was required to discriminate the "oddball" and remember the number of times it was presented.

Auditory Task: This task required approximately 8 minutes. The subject was requested to sit quietly in front of the test screen and listen to auditory stimuli coming from a speaker located 3 meters in front of him. The stimuli consisted of two different tones occurring on a background of white noise. One of the tones occurred with a random inter-stimulus interval (mean = 2 sec) 80% of the time at a frequency of 1000 Hz. This tone was to be ignored. The other tone was designated as "oddball" and was to be reported at the end of the session. The frequency of the "oddball" was wideband and designed to roughly simulate what a sonar operator might hear in real situations. The duration of the "oddball" was approximately 80 milliseconds. The ambient sound levels at the position of the subject's head during the task were 63 dBA baseline (instrument fans, etc.), 67 dBA when the white noise background was on, and 67 dBA during the tone. The intensity of the "oddball" was not measurably different from the white noise. Performance on the task was defined as the accuracy in counting the number of "oddballs". There were 60 "oddballs" for each 8 minute trial.

EEG Recording: Grass silver cup electrodes were attached to the scalp at T3, T4, C3, and C4 with collodian. Impedances were 5 k ohms or less. EEG was amplified X1000 by Grass model 12A5 amplifiers and inputted to a DEC MINC 11/23 computer. Movement artifact rejection was accomplished through software. The data reported here were from the C4 lead only. Furthermore, only the RVP task data were used to test hypotheses.

The mean age of the subject sample was 22 years (range 18 to 37). Each was asked to return for a second recording session within several days. The total preparation and data collection period required slightly less than one hour per subject. Light, sound and temperature levels were kept constant.

Following each recording session, the visual and auditory ERPs were plotted. For each subject there were 32 ERPs (4 tasks x 4 electrodes x 2 sessions).

Data Reduction: Grand means (across subjects) were computed separately for session 1 and session 2 to determine group consistency. The grand means were obtained by signal averaging across the sample for a given condition. For this report, the grand means are given for the reversal pattern "oddball" stimulus condition on the visual and auditory tasks. To test the hypothesis that the ERPs would differentiate the trained from the non-trained sonar operators and to measure the reliability of the endogenous ERP components, windows were defined based on the morphology of the grand means. Consistent components that showed a peak at 150, 200 and 400 msec were identified. Amplitude and latency values of the endogenous components within the windows then comprised the distributions on which statistical tests of the hypotheses were made. These windows were defined as follows:

Pattern Reversal Task

window N150: 150 msec $\pm$ 50 msec

window P200: 200 msec $\pm$ 50 msec

window P400: 400 msec $\pm$ 100 msec

Auditory Oddball Task

window N200: 200 msec $\pm$ 50 msec

window P400: 400 msec $\pm$ 100 msec

N150 is a negative component at 150 msec and N200 is a negative component at 200 msec. The two positive components occurred at 200 msec and 400 msec.

RESULTS

Reliability

The grand means of the visual ERPs are shown in Figure 1 and for the auditory ERPs in Figure 2. It can be seen from Figures 1 and 2 that at least for grand mean ERPs, there are major endogenous ERP components that may be consistent over time in this population.

Using the windows as defined in the methods section, the distributions of amplitudes and latencies of individual components were obtained. A summary of the means and standard deviations of these distributions is given in Table 1. The individual reliability coefficients (Pearson) for the amplitudes and latencies of the major components are summarized in Table 2. Each correlation is based on the distribution of amplitude and latency measured on session 1 and session 2. Some of these components appear to be sufficiently reliable over sessions to warrant their inclusion in a prediction equation. However, it is also clear that several measures, particularly latency measures of the very slow components, are not reliable.

Training

The important question of the effect of training on endogenous ERPs was approached in a similar way. Twenty sonarmen with no training and twenty sonarmen with at least 3 years of training on sonar displays were identified. The mean number of years of training in the latter group was 5.7 years.

Table 1: Means and standard deviations for the major endogenous components for the visual and auditory tasks for 20 trained and 20 untrained subjects.

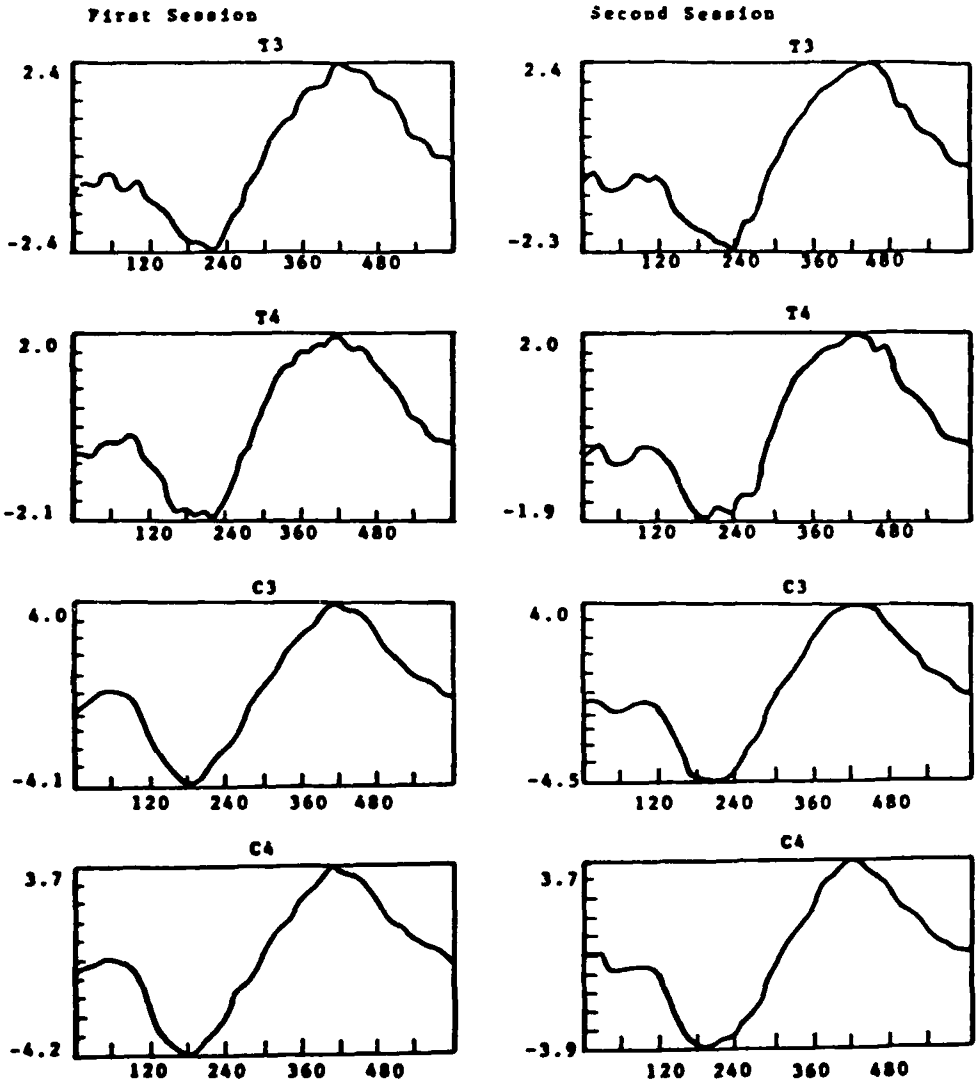
SESSION 1

	Trained				Untrained			
	Amp		Lat		Amp		Lat	
	X	SD	X	SD	X	SD	X	SD
Visual:								
N150	-6.00	2.90	129	31.66	-4.48	2.47	120	29.02
P200	4.46	3.89	216	17.86	4.38	3.32	209	28.09
P400	7.79	2.94	398	48.29	6.48	3.89	395	56.80
Auditory:								
N200	-5.79	2.21	195	26.25	-6.00	2.53	190	44.36
P400	5.49	2.31	438	42.70	5.77	3.16	421	69.47

SESSION 2

	Trained				Untrained			
	Amp		Lat		Amp		Lat	
	X	SD	X	SD	X	SD	X	SD
Visual:								
N150	-5.20	2.55	123	34.94	-4.54	2.63	145	19.09
P200	4.15	2.54	205	61.62	4.02	3.23	213	18.89
P400	10.06	4.54	398	36.64	8.48	4.11	404	44.98
Auditory:								
N200	-6.11	2.10	188	40.36	-6.29	2.30	192	42.64
P400	6.41	2.68	412	54.32	5.55	2.08	432	54.57

Figure 1. Grand means for the auditory task. Amplitude measurements are in microvolts, and latency measurements are in milliseconds. (N=40)



To test the hypothesis that the individual endogenous components differentiate test sessions and amount of training, a 2x2 ANOVA was done for each component. Although it appeared that there was an increase in amplitude across sessions, there was no significant sessions main effect for the visual task. Nor was there a significant main effect for training. The amplitudes across sessions for the auditory task did not differ significantly in the auditory grand mean ERPs (Figure 1). ANOVA's for the auditory amplitudes and latencies revealed no significant sessions effects. The conclusion is that the endogenous components of visual and auditory ERPs, as generated by these particular tasks, are consistent over sessions and are not changed as a result of training. However, there is little evidence for high reliability of the components under the conditions of the present study. A possible confounding variable was age as a t-test of the difference between mean ages of the two groups was significant. The means were 20.6 for the untrained group and 25.3 for the trained group, $t = 4.13$, $P < .05$.

DISCUSSION

This study can be conceived of as a 2x2x4x4x4 multivariate design for which the main effects were training (trained vs. untrained), reliability (Session 1 vs. Session 2), ERP component (N150, P200, P400), EEG source (T3, T4, C3, and C4), and task (alternating checkerboard, background pattern, reversal pattern, and auditory oddball). There were repeated measures to examine ERP for reliability, ERP component, EEG source and task. Although the various interactions may be of interest, the primary goal of the present study was to determine the reliability of ERP components and the effects of training. Amplitudes and latencies of the components constitute the primary dependent variables. The questions of reliability and effects of training were addressed directly with a 2x2 analysis of variance. The results of that analysis showed that the ERP components are consistent over testing sessions and that training, at least for the range tested here, probably does not have an effect on the major endogenous ERP components. In addition, the interaction between sessions and training was not significant indicating that the reliability of ERP components is probably not confounded by the amount of training received. A test of the reliability of individual components was obtained by measuring the correlation between Session 1 and Session 2 and generally indicated that only a small number of components are

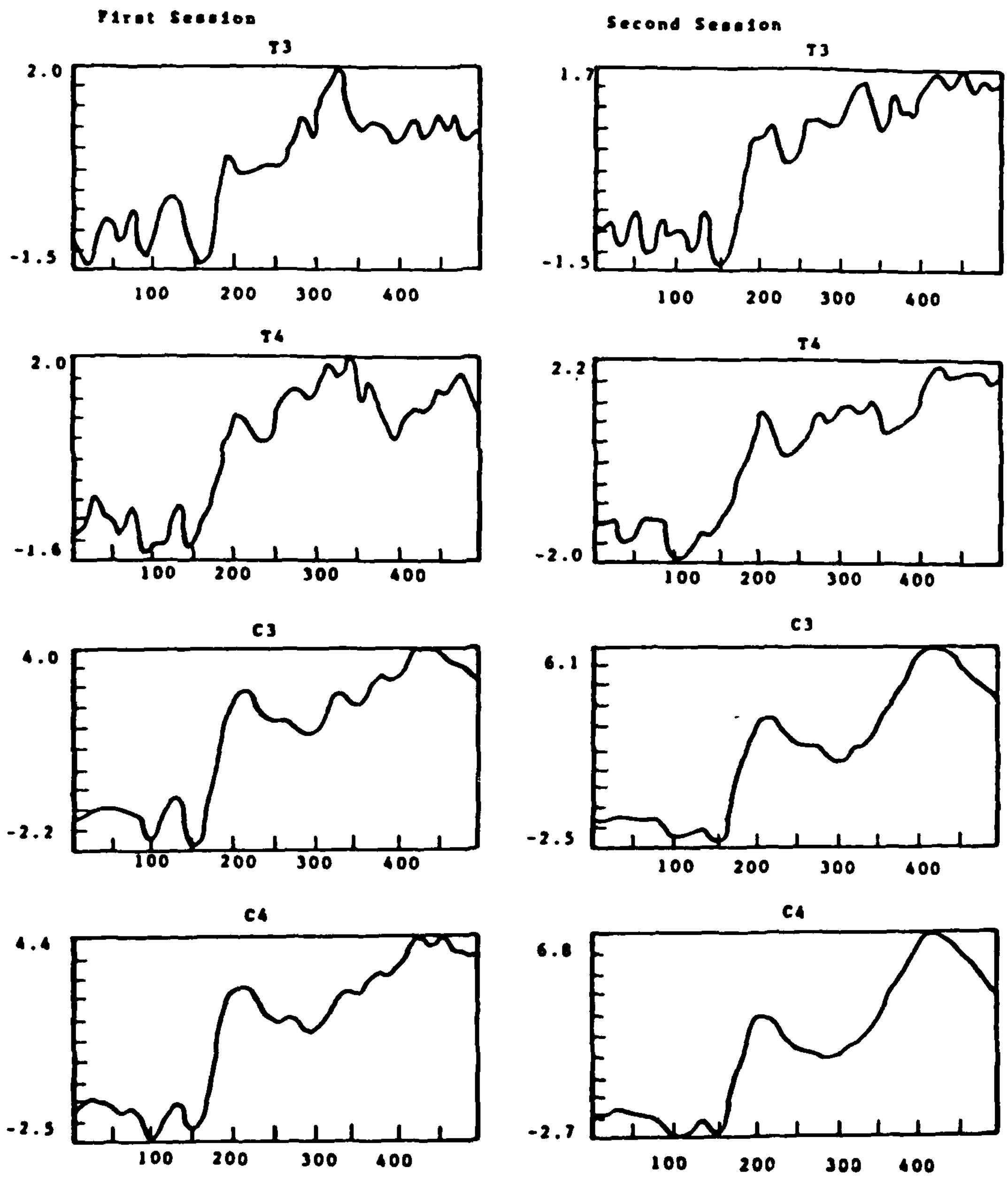
Table 2: Pearson correlations for session 1 and session 2 for the major endogenous components for the visual and auditory tasks with amplitude (N,P), latency (L), and trained and untrained subjects.

	TRAINED		UNTRAINED		COMBINED	
Visual:	r	p	r	p	r	p
N150	.55	.006	.17	.234	.39	.007
P200	.58	.003	.16	.254	.35	.012
P400	.30	.096	.34	.070	.34	.015
L150	.45	.015	-.09	.356	.21	.098
L200	.30	.059	.01	.477	-.15	.18
L400	.40	.042	.31	.093	.34	.015
Auditory:						
P200	.52	.061	.64	.023	.59	.003
P400	.62	.027	.80	.002	.67	.001
L200	.15	.343	.12	.040	.30	.098
L400	.41	.117	.58	.040	.46	.021
	N = 20		N = 20		N = 20	

reliable. There is another aspect of the reliability test that should be mentioned. One of the concerns that came up when the neurometric program was first designed was that a significant first-exposure effect might appear. Reliable responses are sometimes not obtained until the subjects have visited the lab a few times. This could be due to subject nervousness or because the subjects are not familiar with the procedure. The low reliability in the present study supports that view.

The studies by Nataanan (13) and Hillyard (14) report negative components associated with auditory information processing and found these components to be maximal, at least in terms of their amplitudes, along the midline. In the present study, the major components that were related to auditory and visual information processing are positive and extend out beyond 400 msecs. One reason that might account for the difference between the results of the present study and those other studies is the electrode positions. In the present study EEG sources from the lateral surfaces of the individual hemispheres C4 rather than midline CZ sources were chosen. The reason for this electrode placement was based on results from other

Figure 2. Grand means for reversal pattern (RVP) task. Amplitude measurements are in microvolts, and latency measurements are in milliseconds. (N=40)



Navy laboratories' studies (3, 4). They reported that some measure of lateral asymmetry might optimize the chances of discovering relevant ERP components related to high level sonar performance.

Both the auditory and visual ERP components associated with the "oddball" paradigm consist of a negative component at approximately 200 msec and a positive component at something greater than 400 msec. The observation of an N200 component for this type of task is consistent with reports in the literature (13, 14). Of particular interest, however, is the late positive component. Why does this component, which in terms of information processing models may reflect the response selection and response output segments, appear approximately 100 msecs later than the usual P300 wave? One possible explanation is that the EEG sources are over the lateral aspects of the hemispheres rather than along the midline. Perhaps the relevant brain activity that has to do with the recognition of an "oddball" stimulus is actually occurring down along the regions overlying the hippocampus rather than along the longitudinal fissure. In support of this contention is the work of Okada (15), who reports evidence based on magnetoencephalographic recordings that the brain regions most likely associated with the slow components may be in the hippocampus. Further support for the contention that the ERP components studied here are functions of hippocampal activity can be derived from the paper of Schmajuk (16). His extensive and thorough review of psychological theories of hippocampal function leads to the conclusion that at least internal inhibition, response inhibition, attentional shift, attentional "tuning out," recognition memory, long term memory selection, contextual retrieval, spatial memory, working memory, and "chunking" are primarily functions of the hippocampus. If that is in fact the case, then recording electrodes placed laterally at the central and temporal regions would seem to be in a better position to record the N200 and late positive components than would electrodes placed along the midline.

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I. RELIABILITY AND RELATION TO TRAINING

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The large volume of basic research on the relationship of endogenous ERP components to cognitive processes is leading to applications in areas other than clinical. The present work is attempting to develop prediction equations based on measurements of ERP components and will enhance the selection criteria for workers performing complex cognitive tasks, e.g., sonar operators, aviators and air traffic controllers. Several endogenous ERP components from 40 operators were shown to have fairly good individual reliability for amplitude but not latency measures. Grand means for both visual and auditory tasks were consistent over days. The effect of training on the major components from 100 to 500 msecs was unremarkable with no significant differences on amplitudes or latencies.

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